STANDARDS IN CONTROL AND PROTECTION TEHNOLOGY FOR ELECTRIC POWER SYSTEMS

Daniel COSTIANU[1], Nicoleta ARGHIRA[2],
Ioana FĂGĂRĂŞAN[3], Sergiu St. ILIESCU[4]

Abstract: The features of the standard IEC 16850 with respect to intelligent applications in substations are summarized. It is shown how modeling of functions independently from its allocation to devices allows optimizing existing applications and opening up for future intelligent applications. The data model provides all information in a substation needed not only for control and protection functions but also about the IEDs and the switchgear configuration.

1. Overview

The task of protection and control in substations and in power grids is the provision of all technical means and facilities necessary for the optimal supervision, protection, control and management of all system components and equipment in high and medium-voltage power systems.

The task of the control system begins with the position of the HV circuit-breaker and ends in complex systems for substation automation, network and load management as well as for failure- and time based maintenance. For all of these functions the data acquisition at the switch yard and – if applicable – the command execution at the switch yard are part of the network control and management.

Figure 1 provides an overview of the functions and subsystems that make up the control technology in the context of electric power transmission and distribution. The purpose of these secondary systems is to acquire information directly at the high- and medium-voltage apparatus in the substations and to allow their safe on-site operation, including the secure power supply of all their parts.

Modern automation technology provides all the means necessary for processing and compressing information at the actual switchgear locations in order to simplify and secure normal routine operation. This allows more efficient use of existing equipment and quick localization and disconnection of faults in case of troubles, thereby also reducing the load on the communication links and in the network control centers.

Protection devices are required to safeguard the expensive power equipment and transmission lines against overloads and damages. Therefore, they have to switch off very quickly short circuits and earth faults and to isolate very selectively the faulted or endangered parts in the power system. They are thus a major factor in ensuring the stability of the power system.

The purpose of the power system control as a subdivision of power system management is to secure the transmission and distribution of power in the more and more complex power systems by providing each control centre with a continually updated and user friendly overall picture of the entire network.

All important information is transmitted via communication links from the substations to the control centre, where it is instantly evaluated and corrective actions are taken.

The growing amount of data acquired, the increasing communication bandwidth and the performance and memory capacity of modern computers have resulted in replacement of conventional mosaic panels for direct process control by computer based control systems with screens video based displays. In a few cases, conventional mimic panels are still kept for power grid overview.

Load management is directly influencing the system load, e.g. with the help of ripple control communication via power network. It is selectively disconnecting and reconnecting consumers or

---

[1] Student, University Politenica of Bucharest, Power Engineering Faculty
[2] Student, University Politenica of Bucharest, Power Engineering Faculty
[3] Conf. Dr. Ing, University Politenica of Bucharest, Computer Science and Automatic Control Fac
[4] Prof. Dr. Ing. University Politenica of Bucharest, Computer Science and Automatic Control Fac

consumers groups. On the basis of actual and forecasted load figures it is possible to level out load curves, to make better usage of available power resources, or to buy or sell energy on the market.

Due the increase of automation functions, the more complex protection concepts and the least partial integration of the protection into the control systems, the overall system of control, monitoring and protection functions is called substation automation system. The terms 'digital' and 'numerical' apply for all microprocessor based devices with identical meaning.
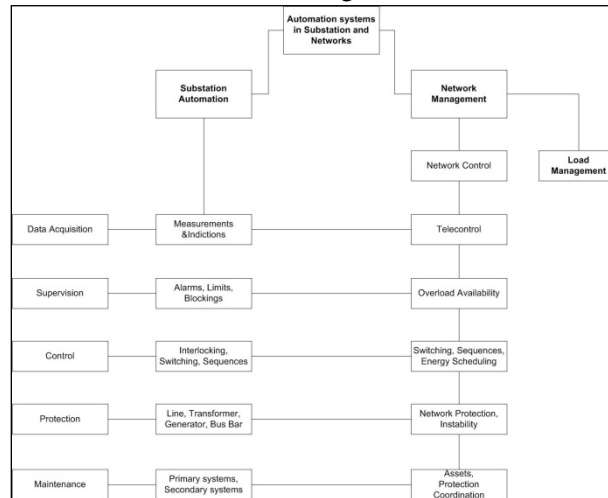

FIGURE 1. FUNCTIONS AND SUBSYSTEMS OF AUTOMATION IN SUBSTATIONS AND NETWORK

2. Protection

Various protection devices in power systems with rated voltages > 1kV are available to protect generators, transformers, cables, busbars and consumers. The purpose of these devices is to detect faults and to switch off and isolate these selectively and quickly from the network as a whole so that the consequences of the fault are limited as much as possible. With today's high fault current levels and highly integrated networks, faults have far-reaching consequences, both direct (damaged equipment) and indirect (loss of production). Protection relays must therefore act very fast with the greatest possible reliability and availability, however also very selectively, to not switch off parts where it is not needed…

Relays can be divided into various categories.

A basic distinction with respect to function is made between switching (contactor) relays and measuring relays.

The relays used for protection purposes, together with supervisory relays, fall into the category of measuring relays and appeared according to their technology first as electromechanical and later as solid-state measuring relays. Today new protection relays are nearly exclusively numerical relays, i.e. based on software running in microprocessors. Therefore, more and more the term protective device is used instead of protection relay. More precisely, there are protection functions which are implemented in devices singly or in combination with other functions. Protection functions supervise dedicated values of the power system or of its components and respond very quickly and selectively if critical limits are exceeded.

There are also protective devices for direct current (DC), but in the context of this paper, only the protection of circuits with alternating current (AC) is described. Important for measurements in multi-phase systems, common is the three-phase system, is that values may be single-phase or three-phase related. In addition, the sinusoidal voltages and currents are shifted against each other by the so-called phase angle. The sinusoidal values may be also represented as rotating phasors with amplitude and angle facilitating a lot of protection algorithms.

Nearly all protective devices are today integrated in some kind of systems requesting information like start and trip events from the protection function(s) and providing access to these e.g. for changing

parameter sets. Numerical relays provide often also disturbance recording and, therefore, disturbance recorder file transfer over a serial link. All this information has to be exchanged over the so-called station bus according to IEC 61850 or one of the older proprietary protocols.

At the output of protective devices, there are switching relays which open e.g. the circuit breaker by closing the trip circuit. These relays act normally also as galvanic separation between power system equipment (primary technology) and the substation automation system including protection (secondary system). It is important that the output (trip) relays are able to switch the applied high currents and to not stick together. Because of their importance for the protection function, they are supervised in most cases.

An alternative not commonly used up to day are electronic components like thyristors for switching the trip circuit.

If not only the values from the instrument transformers but also the trip commands are transmitted serially via the so-called process bus to some breaker electronics integrated e.g. in the drive, then no such switching relays exist anymore. Supported by the communication standard IEC 61850 such solutions will dominate the future, especially since they allow also transmitting current and voltage samples both from non-conventional and conventional instrument transformers.

2.1. Advantages of numeric relays

The numerical relays mentioned above with up-to-date microprocessors (µP) provide a lot of important benefits:

Analog variables are digitized (A/D conversion) at the input card of the device and preprocessed if applicable. The trip decision is made in the microprocessor and, therefore, allows considering any complex conditions needed by the protection function. The resulting protection is much more adaptive regarding the power system conditions as any previous protection technology.

Parameters determining the behavior of the protective device are loaded and changed from outside via communication interface. Also dynamically self-adapting protection is feasible.

Several protection functions can be combined in a single device and executed in parallel (multi-functional devices). Functions from build-in libraries may be activated or downloaded from external libraries.

Numerical devices have a continuous self-supervision. Details depend on implementation.

Configuration and setting of the devices may be done over communication interface either locally by a laptop or from the remote workplace of the protection engineer. Consistency and plausibility checks support this work.

Opto-coupler inputs allow the potential-free input of external signals.

Serial interfaces support both the integration into substation automation systems andthe connection of properly equipped process devices like instrument transformers and switchgear. A manual or automatic transmission of events and disturbance recorder files is possible. The standard for all this serial communication is IEC 61850.

In substation automation systems all events and alarms may be displayed in dedicated lists at the screen of the operator, and archived for later analysis.

Events and disturbance recorder files may be transmitted to a remote, centralized workplace for a comprehensive fault analysis.

Storage facilities for events and disturbance files allow to buffer data so that these are not lost in case of a communication interrupt. They provide also the transmission of data on request only.

Besides protection functions the same numerical device or devices out of the same device family allow performing also control and monitoring functions. In most distribution substations, a single device comprises already all protection and control functions needed in one bay.

3. Control, measurement and regulation (secondary systems)

Secondary systems are all those facilities needed to ensure reliable operation of the primary system, e.g. of the HV substation. They cover the functions of controlling, interlocking, signaling, monitoring, measuring, counting, recording and protecting. The power for these auxiliary functions is taken from batteries, so that they continue to work also in the event of network faults. Whereas in the past conventional techniques were used for decentralized control, e.g. from a local panel, this can now be done

using computer based substation control techniques, often called 'substation automation', with or without protection.

The interface that this necessitates, is moving ever closer to the process, i.e. to the primary system. How near this interface can be brought to the process depends, forexample, on how practical and reliable it is to convert from electromechanical methods to electronic (numerical) techniques, or whether the information to be transmitted can be provided by the process in a form which can be directly processed by the electronics. The communication standard IEC 61850 even defines a serial interface to the process, which provides sampled analog values of voltage and current from the instrument transformers or sensors.

Today, overall network management is undertaken by computer-assisted systems based at regional or supra-regional control centers and load-dispatching stations. The conventional means to connect these to the substation is via remote terminal units (RTU). If however a computer based substation automation system exists, the RTU can be reduced to a protocol converter to the SA system. The trend to use the IEC61850 up to the network control can reduce this even further to a data filtering and concentrating unit.

3.1. Microprocessor and conventional secondary systems compared

With conventional secondary systems, the various functions are performed by separate devices (discrete components) which mostly work on hardwired and analogue principles and represent different technologies.

The resulting situation is as follows:
– Each task is performed by devices using different technologies (electromechanical, electronic, solid-state or microprocessor-based).
– These discrete devices may require many different auxiliary voltages and power supply concepts.
– The connections between the devices and with the switchgear require a great deal of wiring or cabling and means of matching.
– The data from the switchyard equipment has to be supplied several times, i.e. dedicated for the inputs of protection, control, interlocking etc., making the supervision of interfaces difficult .
– Checking the performance of the individual devices is accompanied by complex verification of the overall performance.

With the new automation technology for substations, the focus is on the system and its function as a whole.

Numerical methods are employed for process-near functions using programmable modules based on microprocessors.

The distinguishing features of the new automation technology are:
– Use of the same microprocessor-based platform for the implementation of all functions, either single or in many combinations.
– Standardized power supply and common supply concept facilitating the system layout.
– Serial data transfer (bus technique) minimizing wiring.
– Fiber optic cables are used in the substation reducing the cost of established adequate electromagnetic compatibility.
– Multiple use of the data from the switchgear.
– Self-diagnosis with continuous function check reducing the periodic testing of overall system and subsystems.
– No dedicated effort for recording events in the correct time order with a resolution of about 1 ms.
– Reduced space requirements.

Another major innovation of the new approach is the screen based human-machine interface (HMI). While the access interface to conventional secondary technology is focused on switch or mimic control panels with switches, buttons, lamps and analogue instrumentation, access to the new automation systems is usually given by a display at bay level and by screen-based operator places all with a keyboard and a mouse. This is valid both for the station level in the substation and the network control level. Operation is mostly application near and menu-guided, no programming or ccomputer skills are necessary.

3.2. *IEC 61850 – the communication standard within electrical substations*

Each new substation automation system should use IEC 61850 – mentioned already many times above - as its communication protocol. This only globally recognized communication standard is based on Ethernet, allows direct communication between any of the connected devices, and supports communication within the system hierarchy levels as well as between the hierarchy levels, as well as process near applications. To guarantee real time performance, classical Ethernet busses have not to be used, but only switched Ethernet networks. Further the priority handling and VLAN features as defined in the Ethernet standard have to be supported by the switches. For availability reasons the networks are mostly ring based instead of tree based. The point – point connection between devices can be electrical for short distances within a screened environment, otherwise optical as described already above.

IEC 61850 offers much more than just a communication protocol to connect devices of different manufacturers. Its uniform data model with standardized semantics and the standardized description of substation automation configurations including their functional connection to the switchyard (Substation Configuration description Language) supports uniform maintenance of all secondary devices, provides long life time of engineering data within a system configuration, supports the exchange of engineering data between the engineering tools of different manufacturers, und reduces the effort for engineering and maintenance.

Because of its flexibility and comprehensive features there are further standardization efforts going on to use IEC 61850 also for communication to the network control centre and between protection devices in different substations. Data model extensions for hydro power plants and distributed energy resources are in work also.
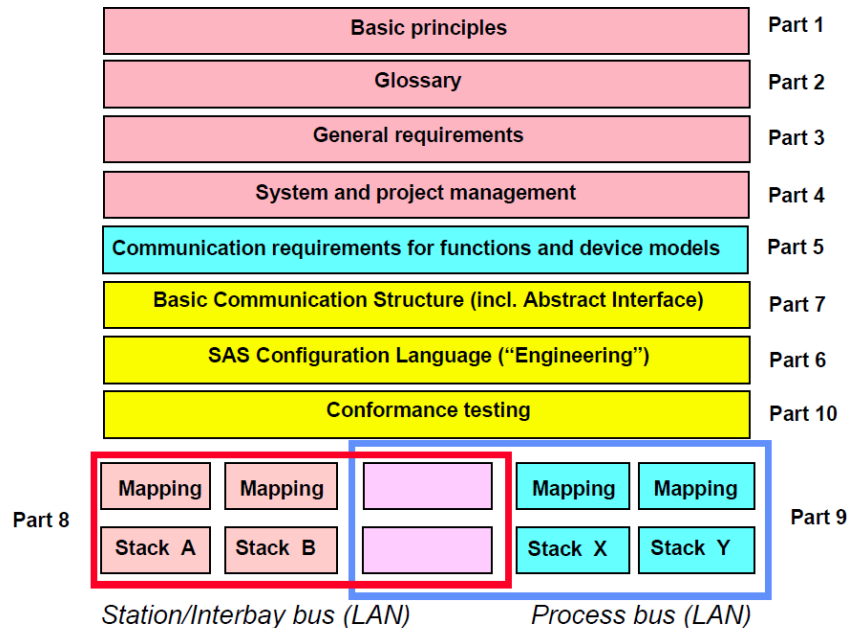

FIGURE 2.STRUCTURE OF THE STANDARD IEC61850 "COMMUNICATION NETWORKS AND SYSTEMS IN SUBSTATIONS" [6]

3.3. *IEC 61850 Substation Model*

At the "process" layer, data from Optical/Electronic Voltage and Current sensors as well as status information will be collected and digitized by the Merging Units (MUs). MUs could be physically located either in the field or in the control house. Data from the MUs will be collected through redundant 100MB fiber optic Ethernet connections. The collection points will be redundant Ethernet switches with 1GB internal data buses and 1GB uplinks that support Ethernet priority and Ethernet Virtual LAN (VLAN).

VLAN allows the Ethernet switch to deliver datasets to only those switch ports/IEDs that have subscribed to the data. In migrating to Process Bus implementations, manufacturers will need to provide the ability to integrate data from existing CTs and PTs with the data from the newer Optical/Electronic sensors. A redundant synchronization clock architecture will also have to be addressed. In this architecture, upon detection of failure of Clock 1, Clock 2 will have to automatically come on line and continue providing sampling synchronization.
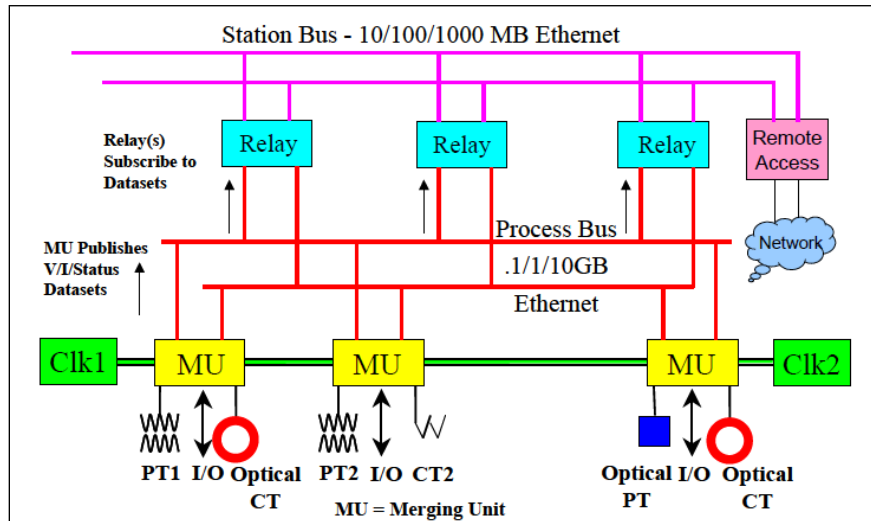

FIGURE 3. IEC SUBSTATION MODEL

At the substation level, a Station Bus will exist. Again, this bus will be based today on 10MB Ethernet with a clear migration path to 100MB Ethernet. The Station Bus will provide primary communications between the various Logical Nodes, which provide the various station protection, control, monitoring, and logging functions. Communications will operate on either a connection oriented basis (e.g. – request of information, configuration, etc.) or a connection-less basis (IEC Generic Object Oriented Substation Event - GOOSE). Again, a redundant communication architecture is recommended as application of IED to IED data transmission puts the communication system on the critical path in case of a failure.

Finally, this architecture supports remote network access for all types of data reads and writes. As all communication is network enabled, multiple remote "clients" will desire access the wide variety of available information. Typical clients would include local HMI, operations, maintenance, engineering, and planning. The remote access point is one logical location to implement security functions such as encryption and authentication. This implementation un-burdens the individual IEDs from performing encryption on internal data transfers but still provide security on all external transactions.

4. Conclusions

IEC 61850 is now released to the industry. This standard addresses most of the issues that migration to the digital worls entails, especially, standardization of data names, creation of a comprehensive set of services, implementation over standard protocols and hardware, and definition of a process bus. Multi-vendor interoperability has been demonstrated and compliance certification processes are being established. Discussions are underway to utilize IEC61850 as the substation to control center communication protocol. IEC61850 will become the protocol of choice as the utilities migrate to network solutions for the substations and beyond.

REFERENCES

[1] Mihoc, D, Iliescu, St. S, Făgărăşan Ioana, Automatizarea sistemelor electro- si termoenergetice, Editura Printech, Bucureşti, 2008
[2] Mihoc D, Făgărăşan Ioana, Oniţa Calotă, Protecţii prin relee, Editura Printech, Bucureşti, 2007

[3] ***, ABB Switchgear Manual 11th revised Edition, Edited by Hennig Gremmel for ABB AG, Mannheim, 2006

[4] Brand K-P, Lohmann V, Wimmer W., Substation Automation Handbook, Utility Automation Consulting Lohmann, Bremgarten, UAC 2003, (www.uac.ch)

[5] Brand K-P, The Standard IEC 61850 as Prerequisite for Intellingent Applications in Substations, Power Engineering Society General Meeting, 2004. IEEE Volume , Issue , 6-10 June 2004 Page(s): 714 - 718 Vol.1(http://ieeexplore.ieee.org/iel5/9451/30010/01372909.pdf)

[6] Andersson L, K-P Brand, The Benefits of the Coming Standard IEC 61850 for Communication in Substation, Southern African Power System Protection Conference,2002

[7] Grimoni J A B, Lopes V J S, Nakao O S, Using LabVIEW in a Mini Power System Model Allowing Remote Access and New Implementations, International Conference on Engineering and Education 2007, (http://icee2007.dei.uc.pt/proceedings/papers/278.pdf)

[8] Le Kim Hung, Thach Le Khiem, De Mesmaeker I, The Advantage of Standard IEC61850 in Protection and Substation Automation Systems, International Symposium on Electrical & Electronics Engineering, HCM City, Vietnam,2007

[9] IEEE PES-PSRC WG I16 Report, Understanding Microprocessor-Based Tehnology Applied to Relaying, 2004

[10] Mason, C. Russel, The Art and Science of Protective Relaying, (http://www.geindustrial.com/pm/notes/artsci/index.htm)

[11] Drew Baigent, Adamiak M, Mackiewicz R, IEC 61850 Communication Networks and Systems In Substations: An Overview for Users

[12] G. Brunello, Microprocessor-based relays - an enabler to Scada integration, Electricity Today, Issue 4, 2003, page 10-1, disponibil la http://www.electricity-today.com/et/issue0403/microproc_based_relays.pdf

[13] Costianu D, Fagarasan Ioana, Iliescu S, Evoluţia sistemelor de protecţie a instalaţiilor energetice. Avantajele noului protocol de comunicaţie IEC 61850, Sesiunea de Comunicări Ştiinţifice Studenţeşti – Mai 2008